Quarterly Technical Summary

General Research

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Lexington, Massachusetts

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 November 1967 through 31 January 1968. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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INTRODUCTION

This section of the report reviews progress during the period 1 November 1967 through 31 January 1968 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 November 1967 through 15 February 1968

PUBLISHED REPORTS

Journal Articles*

JA No.			
2818A	Improved Method of Optimizing Longitudinal Magneto-Optical Transmission-Scattering in Thin Magnetic Films	D.O. Smith K.J. Harte	Optica Acta 14, 351 (1967)
3004	The Oxidation of Aluminum Films in Low-Pressure Oxygen Atmospheres	C.T. Kirk, Jr. E.E. Huber, Jr.	Surface Sci. 9, 217 (1968)
3039	Wave-Optical Aspects of Lorentz Microscopy	M.S. Cohen	J. Appl. Phys. 38, 4966 (1967)
3063	Books and Conference Proceedings	K.J. Harte D.O. Smith	Magnetism and Magnetic Materials Digest (Academic Press, New York, 1967)
3083	Changes in the Work Function of Aluminum During and Following Low-Pressure Oxidation at Room Temperature	E.E. Huber, Jr. C.T. Kirk, Jr.	Surface Sci. 8, 458 (1967)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
3121	Ferromagnetism in Films	M.S. Cohen	Accepted as chapter in Thin Film Phenomena by K.L. Chopra (McGraw-Hill, New York)
3166	Recent Developments in Lorentz Microscopy	M.S. Cohen	Accepted by IEEE Trans. Magnetics
3177	Report on Third International Colloquium on Magnetic Films	D.O. Smith	Accepted by IEEE Trans. Magnetics

* Reprints available.

Division 2

JA No.			
3194	Ferromagnetic Properties of Films	M.S. Cohen	Accepted as chapter in Handbook of Thin Film Technology, edited by L.I. Maissel and R. Clang (McGraw-Hill, New York)
JA-General	Review of "An Introduction to Computer Graphic Terminals" by M.H. Lewin	G.D. Hornbuckle	Accepted by IEEE Trans. Electron. Computers

Meeting Speeches*

MS No.			
2147	Photon and Electron Beam Accessed Magnetic Film Memories	D.O. Smith	Colloquium, Syracuse University, 9 November 1967

* Title of Meeting Speech is listed for information only. No copies are available for distribution.

DIGITAL COMPUTERS
GROUP 23

I. INTRODUCTION

Over the past two reporting periods the objectives of a number of separate efforts in the Digital Computers Group were combined to provide a cohesive attack on one of the most important phases of future computer development. The capabilities and interests in computer-aided graphics, large-scale integration (LSI), and computer logic design have been focused on a problem area which might be described as "computer-aided LSI machine design." Such an application can provide a realistic and useful test for the graphical service system now available on TX-2. This should establish in a rigorous way the utility and difficulties of machine-aided graphics in a problem area in which manual techniques are presently unsatisfactory.

There are at least four areas fundamental to LSI machine design which should be directly amenable to machine-aided graphics: (1) logic layout and checking, (2) circuit layout, simulation and manipulation, (3) mask preparation, and (4) testing. It is becoming increasingly clear that if LSI is to reduce the cost of processing power significantly, techniques must be developed for using computers to automate the design process.

The successful implementation of LSI should fundamentally alter the classical tradeoffs between hardware and software and have an enormous impact on total system design. Conversely, the proper exploitation of LSI will depend on developing a machine architecture suited to its unique limitations and advantages. The present research effort in high-density, large-capacity memories will be coordinated with such an effort and will undoubtedly use many of the techniques developed concurrently.

II. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. Microprocessor Design

An experimental processor has been designed to provide a specific vehicle for experimenting with graphical design techniques and to uncover the significant problems involved in designing an all-LSI digital machine. The current design uses only one kind of basic logic chip and (perhaps) one kind of control (read-only) memory chip. For the logic, only four different circuits are required, each made from the basic logic chip by using different metallization (inter-gate connection) patterns. The logic chip has 64, three-input AND-NAND emitter-coupled logic gates and about 40 pads per chip. Approximately 50 total chips (3000 gates or about 20,000 transistors) are required. The control memory will require from 16,000 to 64,000 bits. If an LSI control memory can be constructed using four square mils per bit, the total control memory will take from 16 to 64 chips, depending upon the complexity of the processor being designed. Hence, it is reasonable to consider a 100-chip processor in, for example, a 10×10 array of 60 mil chips for a total of one square inch. The power supply and heat radiation would, of course, dwarf the processor. Assuming an appropriately sized read-write memory, a single processor is equivalent to a small-to-medium size special or general purpose computer.

B. Microsystems

Three-bit parity processing is continuing in an effort to generate more information on yields. Rejected units from the original wafers were mainly the result of alignment and metallization problems. A new mask set has been designed to reduce these problems. The increased yield is expected to make nine-bit parity circuits available for evaluation.

A wafer-chip version of the nine-bit circuit, which requires forming 48 bonds, has been designed. The special wafer bonder is being tested. The completed nine-bit parity circuit will consist of four standard three-bit units bonded to the 175 × 65-mil wafer chip. Yield and performance comparisons between the wafer-chip and LSI versions of the nine-bit parity circuit will be very instructive.

A test chip, containing several transistors, resistors, and sheet resistivity test strips, has been designed. These chips will be fabricated to provide parameter spread data for a worst-case CIRCUS evaluation of a new basic circuit design.

C. Failure Analysis

Evaluation of three-bit parity array failure modes has been made with the aid of a discrete-component model of the circuit and a normally functioning three-bit microcircuit. The initial approach was to simulate failures in the model and observe the effect upon the output, but it soon became apparent that each erroneous output had a plethora of common causes. Examination of input, output, and power supply terminal diode characteristics served to reduce the possibilities to a tractable few, making logical analysis workable. The problem will be more severe in the case of the nine-bit parity circuit which has a lower ratio of terminals to gates.

Once satisfactory techniques are developed in this manner, they will be incorporated into the TIC (Testing Integrated Circuits) program for computer-aided testing.

III. MAGNETIC FILM ENGINEERING

A. Large Capacity Memory

1. LCM Substrate Yields

Testing has been completed on the 131 substrates from the first ten production runs of evaporated composite films. Nineteen of these were acceptable for the memory. The reasons for rejection of the remainder and the point at which they were rejected are given below.

Initial Inspection and B-H Looping after Evaporation	
Thin copper and surface bumps	22
Did not pass magnetic specifications	16
Damaged	1
During Processing	
Copper defects, poor adhesion or low signal	24
Poorly scribed	16
Damaged	10

Final Inspection and Electrical Test

Poor magnetic characteristics	2
Glass surface scratches or pinholes in magnetic or copper layers	21

The nineteen accepted represent 15 percent of the total and 45 percent of those reaching final test. It is quite certain that the large attrition due to poor copper, poor line edges, and damage can be significantly reduced. In one run which had no loss due to evaporation or processing defects, fourteen substrates were processed and nine were acceptable.

2. LCM Stack for TX-2

The stack was assembled under clean conditions and tests were made of the signal and word noise. It was found that about 1 percent of the bits had word noise high enough to make reliable operation questionable. The predominant cause of noise seemed to be capacitive imbalance between word lines and the two sides of the digit lines. An improved circuit configuration decreased the voltage on a word-line group at read time by reducing lead inductance, and lowered word noise to the point that only 0.2 percent of the bits were questionable. The stack has been disassembled to permit installation of the modified group circuits and visual examination for specific causes of residual noise.

The spring-loaded word-line contact design for the extended LCM has been put to use in the TX-2 stack. A full complement of these pressure connector-diode array assemblies has been constructed. They provide more reliable contact and a considerably shortened top-to-bottom substrate interconnection.

3. Film Signal

The signal from a single LCM bit has been measured as 130 microvolts, with 37-nsec width and a 3-mv-nsec integral.

4. LCM Digit Conductors

Ways of improving the edge straightness of digit conductors are being studied. Such factors as conductor material, resist composition and application, methods of exposure and development, and etching will be investigated to determine the contribution of each to conductor quality. Improvement of conductor-edge definition will be beneficial to memories of present conductor density and is considered essential for memories with greater wiring density.

B. New Film Techniques

1. Word-Line Flux Closure

Process was made on two approaches to word-line flux closure of 2-mil-wide lines. The first was electroless cobalt about 0.1-mil thick having a permeability of about 10 up to several hundred oersteds with relatively little hysteresis. This resulted in reducing the word current by a factor of two. The second approach was to smooth the copper with a layer of SiO_2, 0.5-μ thick and evaporate a top magnetic layer nearly identical to the bottom layer. Etching of this

structure is difficult, but those lines which have been successfully etched show a reduction in word current which agrees with theory.*

2. Copper Film Stress Measurements

Substrate temperature and evaporation rates for minimum stress in thick (0.8 mil) copper digit lines are being determined experimentally. A laser is used to illuminate evaporated copper films on thin glass substrates. The reflected light spot diameter is a function of the radius of curvature of the mirror which is determined by the stress in the copper film.

3. Optical Looper

Optical components have been mounted and aligned. The permanent driving and sensing circuitry is nearing completion.

4. Magnetic Film Computations

A computer program has been written for the determination of magnetization distributions in thin-magnetic-film structures having the form of a group of infinite flat ribbons. The infinite dimensions of all ribbon must be parallel, but the cross sections need not be. The program will be useful in the analysis of multifilm magnetic memory structures.

IV. SYSTEM PROGRAMMING

A. Applications Programming

1. Mask Layout

The integrated circuit mask layout program under development has been changed considerably this past quarter. With tape output for a precision mechanical artwork generator now possible, work on photographic mask generation has been temporarily suspended. Preliminary features for upper level metal interconnection have been added but are still under development and not yet usable. Some component geometries have been changed to match revised circuit design parameters.

Several trial layouts of actual circuits have been completed and output tapes made.

2. Constraints

The mathematical characteristics of constraint structures have been explored, with the objective of producing programmable techniques of increased simplicity and generality. It has been established that constraint techniques are applicable to systems of linear relations, even when the relations are not independent, and these techniques are particularly effective for sparse linear systems. Both nonindependence and sparseness are common characteristics of systems of relations arising in on-line applications.

B. Languages

In addition to fixing bugs and helping new users, the effort on the LEAP system has been concentrated in three areas:

*R. Berger, "Demagnetizing Fields of Planar Magnetic Film Structures With One Infinite Dimension," private communication.

(1) Facilities have been added to provide dynamic linkage between LEAP programs and other programs on TX-2.

(2) Both the compiler and the run-time routines have been provided with meaningful error messages.

(3) Documentation for the system has been brought up to date, and a new base-language user's manual is being written.

Currently, we are working on a facility for merging data structures, and on compiling dynamically relocatable LEAP programs. Also, a facility for symbolic debugging and symbolic communication between LEAP programs is being implemented.

C. Debugging

Several new and improved debugging facilities have been made available to the APEX community through Mark 5:

(1) A single-stepping mode of operation enables a user to run a program one instruction at a time.

(2) A set of commands may be assigned for automatic execution whenever a user program traps. The commands are contained in a file which is interpreted when a trap occurs; the contents of the file may be modified whenever the user desires.

(3) A timing facility enables one to determine elapsed time between any two points in his program. One may thus easily time the operating speed of programs for enlightenment or for comparing approaches to writing programs. The accuracy of the timing is correct to tens of microseconds; certain variable APEX overhead may degrade the accuracy to fractions of milliseconds.

(4) A symbolic instruction format is available for examining the contents of user programs and machine state registers. In this format contents of registers are given in instruction format with the index registers and address fields supplied symbolically, when possible.

V. COMPUTER SYSTEMS

A. TX-2 Memory System

The TX-2 memory system is being reorganized to provide for a number of new memories and processors. Although this system was upgraded recently by the addition of the page address mechanism and the new memory bus switch, many outmoded parts of the old memory system remained. The current effort is aimed both at simplifying and standardizing the memory organization.

During the next quarter the computer memory capacity will grow by approximately 50 percent, from about 110,000 to about 160,000 words as the new core and film memory modules are installed. The number of processor spigots in use on the memory bus switch will also grow, from two to four, when the input-output controller (SNAT) and the simulated LSI processor are connected.

B. Displays

The new display sequence using the conic and symbol generators is in operation in TX-2. Projects using the graphical capabilities of the sequence include integrated circuit mask layout

and picture processing. Operation is satisfactory except for line drawing speed. Higher speed is necessary to reduce the flicker rate when complex circuit masks are displayed.

C. Typewriter and Input Keyboard

The TX-2 end of the keyboard/selectric logic has been checked out. The remote terminal logic has been constructed and is ready for checkout. Keyboard modifications will soon be completed. A prototype keyboard design and the printed circuit card for peripheral switches and their encoding diodes are about to be sent for fabrication.

COMPUTER COMPONENTS
GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

Looking of one or more uniaxial anisotropy relaxation processes in Permalloy films has been observed after exposure to oxygen (air). A nonmagnetostrictive Permalloy film was deposited at 250°C and held at that temperature for 4 days, during which time it was subjected to a series of rotating and parallel anneals. A relaxation plateau of about 50 mOe was measured in the frequency range 10^{-2} to 10^{-1} Hz. Very little peaking was observed, indicating a broad distribution of relaxation times. At 109°C the plateau increased to 75 mOe, and at 40°C to 120 mOe. The sample was then exposed to atmosphere and re-measured within a few minutes at which time the plateau was found to have dropped to 30 mOe. Thus a relatively large contribution to the uniaxial anisotropy was presumably prevented from re-ordering by oxygen, providing strong evidence for a vacancy mechanism.

A new system for rotating anneal experiments is being built into the Varian ultrahigh vacuum system. A set of orthogonal coils has been designed and built which will produce a fivefold increase in field to ≃ 200 Oe, and the oven, sled and coil assembly has been installed in the vacuum system. A multiple pulsing circuit has been added which allows the measuring sequence of field pulse, spike and readout to be repeated for any preset number of times up to 64. This will save time on slow anneals by collecting more data at each measurement portion of the annealing cycle, permitting an order of magnitude slower annealing.

B. Lorentz Microscopy

In order to make a quantitative investigation of magnetization ripple, it is necessary to know the defocusing distance used in taking Lorentz micrographs by the defocused mode. Considerable effort has been made to calibrate the electron microscope using mechanical measurements for long defocusing distances and variations of the objective lens current for short defocusing distances.

II. PEBA MEMORY SYSTEM

The recently proposed photon and electron beam accessed (PEBA) magnetic-film memory system* has been deficient in reducing shot noise from unselected bits to an acceptable level. A satisfactory solution to this problem appears to be possible by using temperature-dependent properties of magneto-optical spectra in the rare-earth iron garnets (REIG). Two different temperature effects can be distinguished: thermal shifting of the position of spectral lines, and thermal pumping to the state from which absorption during readout is to take place. Furthermore, the properties of the REIG are such that the fundamental signal-to-noise ratio for a

*D. O. Smith, "Proposal for a Magnetic-Film Memory Accessed by Combined Photon and Electron Beams," IEEE Trans. Magnetics (December 1967).

single bit is improved by several orders of magnitude when compared with previously considered systems.*

Experiments relating to the PEBA system which are being considered and have in part been initiated include: (a) verification of the predicted frequency response of electron beam heating, (b) production of single crystals and films of REIG, (c) study of the near-infrared spectra of the REIG, (d) magneto-optical conversion matching to REIG films by the use of multilayer dielectric structures, and (e) development of suitable IR lasers and detectors.

III. ELECTRON TRANSPORT

A. Al-Al_2O_3 Triodes

It has been possible to describe the attenuation factor of the collector oxide of a hot electron triode in the form $\exp - (X_m/l_p)$ where X_m is the distance from the metal base to the oxide barrier maximum and l_p is the electron-phonon mean free path in the oxide. The dependence of X_m on collector bias was calculated on the basis of Simmons'† description of Al-Al_2O_3 tunnel barriers. A value of l_p = 10 Å was obtained in fitting this attenuation factor to the observed α vs collector bias curves. This factor still leaves an unexplained attenuation factor of approximately 10^{-2} which is apparently an interfacial factor.

B. Vanadium Oxide

1. Film Fabrication

Films of VO_2, V_2O_3 and their intermediates have been fabricated by several processes including oxidation of evaporated V_2O_3 films, DC sputtering of metallic vanadium in argon-oxygen mixtures, and thermal oxidation of vanadium films in several microns of oxygen at high temperatures, e.g., 720°C. Best results were obtained with thermal oxidation, although better control of oxidation conditions is required in order to obtain single phase films. Thus, for example, some films show single transitions of up to 6 orders of magnitude at temperatures intermediate between the VO_2 and V_2O_3 transitions (65°C and −110°C, respectively), while others display these two transitions separately.

2. VO_2 Film Switching Time

Switching time measurements were made on a 500-Å film sample deposited on a glass substrate. A step of voltage was applied across a 1 × 0.25-mm region of the film and the delay time to heat to the transition point and switch to the ON state was measured. Cooling periods of at least 10 seconds between measurements were used. The delay time data may be represented by the equations:

$$T = \infty \qquad (V < 30 \text{ volts})$$

$$T = 10^{(20V)/6} \text{ seconds} \qquad (30 < V < 45)$$

$$T = 10^{V/11} \text{ seconds} \qquad (45 < V < 65)$$

* D. O. Smith, "Proposal for a Magnetic-Film Memory Accessed by Combined Photon and Electron Beams," IEEE Trans. Magnetics (December 1967).

† J. G. Simmons, J. Appl. Phys. 35, 2472 (1964).

C. Theory of Surface Potential in Metals

We have investigated the role of correlation effects in determining the surface potential for a simple model of a metal-vacuum interface. One point that emerges from the analysis is that the correlation correction to the single-particle energy levels changes sign somewhere slightly below the Fermi surface. This implies a certain cancellation of the correlation effect for physical properties which depend on a reasonable range of occupied states below the Fermi level. An explicit calculation of the Slater average exchange-correlation potential has been made which supports this point of view. At the same time, for many problems of physical interest, only the single-particle states in the immediate vicinity of the Fermi surface are important. We conclude that a Slater average is inappropriate for discussing such problems. Details will be presented in a forthcoming journal article.

PSYCHOLOGY
GROUP 25

I. MAN-MACHINE INTERACTION ON THE IBM 360 MODEL 67

A. Editor System

The Character Stream Editor is essentially finished, although the pieces are not all interlinked. It will be put in service after operational checking, which should take until about 1 March.

In detail, the coding for accessing files and file directories is finished and testing has begun. Capability of the file access routines in the environment of the Mediator is being examined and should soon be assured. The string-matching routines have been fully designed and coding will be finished shortly. The procedure runner is substantially finished and operational testing will start soon, but the handling of procedure formats at the level of the user has received little attention so far.

An initial set of specifications for the Fortran Editor has been received. It will serve as a basis for a first pass at a detailed design by the contractor. An initial set of specifications for the Script Editor – an editor for English text – is being prepared.

B. Mediator and Reckoner

A first working version of the Mediator has been received from the contractor and has passed simple operational tests. The Mediator is in effect an on-line operating system designed to support a library of coherent programs (Sec. II-A), and in particular, to support services like the Reckoner, a facility for array arithmetic and other numerical calculations. The Mediator provides basic services to the program library, e.g., maintaining a directory of programs and data, handling storage space, and suspending the current program, at its request, to run another.

Three kinds of activity are in progress to expedite completion of the Mediator and a Reckoner: (1) Work continues on the basic Mediator routines that remain to be completed, notably those for log-on and log-off. (2) A set of shakedown programs that will exercise the Mediator strenuously is being written. They include programs for creating, adjoining and examining files of text, and they also include facilities for creating a process, i.e., a prestored list of programs that is to be run off automatically. With this facility large, moderately complex sequences of operations can be performed to uncover bugs and test the limits of the system. (3) Work is in progress on the coding of the Fortran "studding," a set of assembly-language subroutines that a Fortran programmer may use to request the services of the Mediator. Final design decisions about the conventions that Reckoner routines will follow are being incorporated in the studding that remains to be coded.

During the coming quarter, an initial Reckoner should be available for use throughout the Laboratory. It should prove attractive because of the relative simplicity of using the system

to carry out numerical calculations. Because of the ease with which users can incorporate their own Fortran routines, it is hoped that the users themselves will contribute routines to the public Reckoner library. Indeed, the implementation of the Reckoner in the Mediator environment is basically an attempt to permit genuine consumers of computer time to build on each others' work and to share the burden of program generation.

II. MAN-MACHINE INTERACTION ON THE TX-2 COMPUTER

A. Coherent Programming

Work continues on the long-term effort to develop coherent programming, for which the APEX time-sharing system was, in part, designed. Coherent programming is a policy governing the construction of a library of programs that are to be used on-line; its purpose is to provide a high probability that programs written by different people can be used together, even when the users are nonprogrammers, and even when the authors of the programs never anticipated that their programs would be used together.

Thus far all the programs in the coherent public library have been written in assembly language, which is costly in programming effort. Although higher level languages that are products of the VITAL compiler-compiler have been available on TX-2 for some months, they could not be used to write programs for the coherent public library. They have been used to write programs that fit into the coherent environment and can be used by their own authors, but these languages were not adequate for writing programs that will obey all the conventions that have been established for the public library.

The most powerful of the existing languages is LEAP, which is similar to ALGOL, but also has the capability for interactive graphics. It was decided that LEAP should be modified to produce programs for the coherent public library. The modifications consist of some minor changes to the compiler, plus a set of twelve LEAP procedures with which the programmer can inspect the string of directions given to his program, check the legality of the inputs on which the directions say to operate, set up files, declare results in the directory, type error messages, and exit from the program in the standard manner. With these procedures the programmer can produce programs that obey all the public conventions.

The initial set of modifications is working, and so the desirability of further modifications is being studied. The programmer still does not have adequate control over error conditions in built-in LEAP functions, such as the logarithm, and the handling of arrays is inefficiently incompatible with the way arrays are handled elsewhere in the library. Other services, such as calling another public program from a LEAP program, must be implemented, and finally, the services provided by the newly written LEAP procedures should be incorporated into VITAL, so that they can become a part of any compiler produced by VITAL.

The language that is generally used to invoke programs from the coherent library – the language that takes the place of what would usually be called a command language – is defined by two programs: the basic translator, which accepts commands from the keyboard, and the process runner, which executes a prestored series of commands that may include parameters and conditional branches. Extensive changes have been made in these two programs. The basic translator may now be operated in several different modes: the user may choose between long and short

error messages, request a typed acknowledgment when the computer has caught up with his input commands, get automatic turn-off of certain input-output devices when he pushes the "Help Request" button, and have his sequence of commands stored in an archive file. Both the basic translator and the process runner now use an error-fielding scheme that achieves faster command translation in the normal case without sacrificing useful diagnostic information in the case of an erroneous command. The new scheme eliminates checking each command before execution; instead, a more sophisticated program waits to process the trap information which will result if the user's command should prove to be unexecutable.

Also, a manual has been prepared describing the programs that belong to the coherent public library but do not belong to the subset known as the Lincoln Reckoner.

B. APEX

Work on the maintenance and evaluation of the APEX time-sharing system has been a major activity this past quarter. Again there has been very little change in the external aspects of the system, but internal changes have resulted in a small increase in the amount of core memory available to users. Among the new external features are limited capability for punching paper tapes, and a more general interpretation of auto-expandability. Previously, auto-expansion was limited to references within the single page adjacent to the upper bound of the existing file; now the file is automatically expanded on a user program reference to any address within the maximum file range.

A major portion of APEX activity has been involved in adapting the system to and recovering from major changes in the TX-2 hardware. The immediate series of hardware changes should result in a major increase in available core memory during the next quarterly period. The efficient use of this new memory will necessitate significant changes to the APEX resource allocation routines. The groundwork for these changes has been under way this past quarter and will continue well into the coming quarter.

Work on magnetic tape routines has been deferred. The routines for handling the new display hardware have been incorporated and are operating satisfactorily.

C. Speech Recognition

The demands of the APEX time-sharing system have resulted in a low level of effort in speech recognition this past quarter, but there has been continuing progress in revising the recognition programs to operate in the time-sharing environment. The phoneme recognition programs are now running and attention is being focused on the limited word recognizer that uses the output of the phoneme recognizer.

III. HUMAN INFORMATION PROCESSING

A serial-position effect has been found under conditions that appear to have theoretical implications about the retrieval of information from immediate memory.

The subject heard a list of digits, and then after a short pause, heard the same list again (i.e., the same digits in the same order), or heard a list that was identical to the first except

that one digit was changed. The first list was presented at the rate of eight or three digits per second, and the second list was presented at the same rate as the first. The subject's task was simply to say whether the two lists were the same or different.

It was found that the probability of correctly recognizing a change was high when the change occurred at the beginning or end of the list, and was low when the change was in the middle; in other words, there was a pronounced serial-position effect of the same kind that is observed in recall.

If one accepts the hypothesis that the serial-position effect in immediate recall is due to the Gestalt properties of the list – i.e., is due to the fact that the ends of the list are better structured – then the present finding casts doubt on the distinction between memory for the order of the items and memory for which items occurred. It would appear that the very fact that an item has occurred is more easily retrieved when the item is fitted into a solid structure than when it is fitted into a shaky structure.

COMPUTER SYSTEMS
GROUP 28

I. COMPUTER CENTER DEVELOPMENT

A measure of the progress and increasing acceptance of the time-sharing system during the past quarter is the fact that normal operations have been expanded to a full eight-hour day, five-day week, with an additional four hours on Saturday. Included in this schedule is the continuous running of a batch monitor which has taken over most of the short, restricted debugging jobs formerly handled by the conventional IBM supplied operating system. The visible migration of work from one system to the other reflects the emerging complementary, rather than competitive, roles of each. The programmer now has the choice of two different types of systems to solve his problem. At the present level of implementation, there are significant advantages in having ready access to such a choice.

Equipment installation has been a dominant theme in the activity of the quarter. Additional primary and secondary storage capacity provided by the installation of a fourth main memory unit and two 2314 disk facilities has resulted in improved system efficiencies and more user accounts for time sharing. In the coming quarter this additional space will be further exploited to provide users of both systems with access to even larger data or program files.

A programming package is being prepared under time sharing to control the operation of two 2250-3 CRT displays installed at the end of the previous quarter. These displays have both graphic and alpha-numeric output capability and may be controlled externally by either a light pen or a set of programmer specified function keys. Among many possible applications, this system would be of particular value for data reduction jobs where content influences the nature of the processing.

In order to keep pace with the demand for data collection facilities, three of the smaller disk drives, released by the installation of the 2314 disk facility on the 360/67, were moved to the 360/40. Because access to information on a magnetic tape is strictly sequential, it is impractical to do other than assign a single tape drive to each separate data gathering line. Such a requirement very quickly puts a low ceiling on the number of lines which can be serviced. But by substituting a disk, with its direct access capability, as the storage medium, it is possible to handle many input lines on a single device. Design and implementation of the necessary changes to the 360/40 multiprogramming supervisor are in progress for this purpose.

II. LISTAR (Lincoln Information Storage and Associative Retrieval System)

Over the past quarter programs have been added to the LISTAR system which give a user the means for defining a new file to the system from a keyboard console. Work continues on programs for adding new data entries to files that have been defined and whose description exists in the Master File.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 November 1967 through 31 January 1968. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary and the Quarterly Letter Report to ARPA.

S. H. Dodd
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DIVISION 3 REPORTS ON GENERAL RESEARCH

15 November 1967 through 15 February 1968

Journal Articles

JA No.			
3102	Observations of 8 GHz Continuum and Hydrogen Recombination Lines in the Orion Nebula	M.A. Gordon M.L. Meeks	Accepted by Astrophys. J.
3145	Observations of Galactic OH Emission	M.L. Meeks J.A. Ball	Accepted by Astrophys. J.
3168	Discrepancies Between Radar Data and the Lunar Ephemeris	C.R. Smith* G.H. Pettengill I.I. Shapiro F.S. Weinstein	Accepted by Science
3199	The 18 Cm Flux of the Unresolved Component of 3C273	J.M. Moran* B.F. Burke* A.H. Barrett* A.E.E. Rogers J.C. Carter J.A. Ball D.D. Cudaback*	Accepted by Astrophys. J.

Meeting Speeches†

MS No.			
2057, 2057A	Interferometric Spectral Line Observations	J.M. Moran A.E.E. Rogers	NEREM, Boston, 1 – 3 November 1967; Colloquium, University of Rochester, 4 January 1968
2130	Time Variations in Microwave OH Emission	J.A. Ball M.L. Meeks	American Astronomical Society, University of Pennsylvania, 4 – 7 December 1967
2160	Theory of Nonthermal Emission of the OH Lines	A.E.E. Rogers	HII Region Symposium, Charlottesville, Virginia, 8 – 11 December 1967

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

SURVEILLANCE TECHNIQUES
GROUP 31

I. SUMMARY

Group 31 operates and maintains Lincoln Laboratory's Millstone and Haystack Hills complex and conducts most of the research centered at these facilities.

At Millstone, emphasis has increased on precision tracking, auroral and propagation studies designed to answer questions important in the development of the Sentinel ballistic missile defense system radars. Ionospheric (Thomson scatter) research continues, together with studies of meteorological disturbances as they affect space communications systems. In the course of this work, layers of clear air turbulence have apparently been observed at altitudes as high as 75,000 feet.

Among other radiometric activities, the Millstone antenna served as one element of a very long base-line interferometer at OH-line wavelengths. Other stations were NRAO (Green Bank), Hat Creek (California) and Onsala (Sweden).

Radiometric techniques were applied in the evaluation of the rerigged Haystack reflector. The efficiency at 16,000 MHz (λ = 2 cm) has been increased by about 40 percent and a good beam is now formed at 35,000 MHz (λ = 8 mm) as well. Equipment is being built to calibrate the PRESS ALTAIR (ARPA long-range tracking and instrumentation radar) on Roi-Namur by the same techniques.

Improvement continues in the X-band planetary radar at Haystack with 400-kW transmitter operation and 50° to 55°K receiving system temperatures now available. Although some planetary observations have been made, emphasis during this period of antenna system improvement has been on the study of past data.

II. SPACE SURVEILLANCE TECHNIQUES

A. Sentinel Studies

The initiation of the Sentinel deployment program has led to a series of consultations with staff members of Bell Telephone Laboratories on propagation problems affecting the predicted performance of that defense system. Informal discussions were followed by a formal request from the Army that the Laboratory assist in the study of such problems. The background of Group 31 staff members in propagation studies, radar studies of the aurora and precision orbit determination methods has made the Group's advice particularly useful in the development of plans for further related studies in these areas.

One of the results of the ten days spent this period on such consultations is the development of an in-house propagation program, which is already under way. Several techniques were devised to observe scintillations in hard-target tracking data using Millstone. Sizable disturbances can be caused by refraction, multipath propagation, and auroral disturbances along the radar line-of-sight. Many of the perturbations of concern at UHF are considerably reduced at L-band, making the requirements for angular accuracy at Millstone quite stringent. An orbital-dynamics

approach has been selected which relies on Millstone's precision orbit-fitting program for the SDS 9300 computer. These programs, MHESPOD and NRTPOD, have been described in previous quarterly technical summaries.

Preliminary results obtained on a large target (Pageos satellite) indicate adequate measurement sensitivity. About 2 minutes of data consisting of 1-second smoothed samples were fitted to a trajectory such that the standard deviations σ were

$$\sigma_{range} = 1.25\,\text{km},\ \sigma_{angle} = 0.005\,\text{deg},\ \sigma_{Doppler} = 1.0\ \text{meter per second}.$$

A means has been proposed for measuring passively variations in angle of arrival of satellite beacon signals at UHF while skin-tracking the same target with the L-band radar. Any satellite that has a UHF beacon and an orbit that makes tracking through the auroral zone possible can serve as a target in such an experiment. A monopulse configuration of dipoles has been designed for application to the radar antenna.

Because of the heightened interest to both Sentinel problems and the approach of high solar activity, the auroral backscatter measurements program has been resumed at Millstone. Auroral echoes were obtained on 11 and 13 January. Computer programs for analysis of these data taken at various pulse lengths and in various antenna scanning modes are now operational.

B. Tracking Support

Approximately one-half day per week at Millstone was devoted to satellite tracking by the MITRE-Millstone radar interferometer. Near the end of this quarter, a 1280-MHz receiver chain was added to the system to provide two-frequency capability (1280 and 1295 MHz) for resolving ambiguities in the interferometer system.

III. LUNAR STUDIES

A. Completion Reports

The investigations conducted at this station under NASA Contract NSR 22-009-106 have now been completed. Results for the average radar scattering properties as well as the radiometric (thermal) emission at 23- and 3.8-cm wavelength have been reported in Volume I of the Final Report under this contract. Volume II, which contains the results of the 23-cm supersynthesis mapping, as well as the fine-grained delay-Doppler mapping at 3.8 cm, will be issued shortly.

B. Planning

The NASA Manned Spacecraft Center at Houston has shown interest in having the 3.8-cm lunar mapping work extended to the entire surface of the moon. It is also desired that observations be made in the transmitted as well as the opposite sense of circular polarization. This will require two-channel receiving capability in the Haystack planetary radar system. A specific proposal to NASA covering this work over a period of 15 months has been prepared.

IV. PLANETARY STUDIES

A. Haystack 3.8-Cm Observations

Observations of echo delay to the planets Mercury and Venus for the purposes of orbit improvement have continued at a reduced rate during this report period. Emphasis has been

primarily on improving the engineering reliability and operational convenience of the planetary radar system.

Reports based on intensive observations of both Mercury and Venus during the period mid-October 1966 through mid-September 1967 are in preparation. It appears that the measurements to test the general theory of relativity, as well as those designed to produce the map of scattering regions on Venus, have proved successful.

B. Interferometric Radar Studies at 3.8 Cm

Data from the observations of the inferior conjunction of Venus taken with the so-called Hayford radar interferometer, described in the last quarterly technical summary, have been reduced during the present reporting period. By transmitting a CW signal from the Haystack antenna and frequency analyzing the received echo, it was possible to resolve the planetary surface scattering into strips parallel to the apparent axis of rotation. Cross-correlation of the complex frequency components obtained at the two sites (Haystack and Westford Communications Terminal) yielded corresponding spatial Fourier components which resolved the scattering along these strips. With 1-Hz frequency resolution and a maximum of 10 fringes along the rotation axis, it was possible to map the hemisphere of Venus which was visible to the radar during inferior conjunction. Overall, the final data reduction gave a map with approximately 100 resolution intervals parallel to, and 20 resolution intervals perpendicular to, the apparent rotation axis of the planet.

For a limited region on the planet surrounding the center of the visible disk, higher resolution was obtained from pulsed-radar data. The pulsed resolution enabled the planet to be further resolved in echo delay, leaving only a twofold hemispheric ambiguity to be resolved by the interferometer.

The maps obtained from the observations show Venus to be smoother on the average than the moon at 3.8 cm, although some regions of the planet exhibit strong radar scattering enhancement. The positions of these regions agree well with those previously reported, if the rotation period of Venus is assumed to be earth-synchronous at 243.16 days retrograde. Since Venus made 8 revolutions relative to the earth between the 1964 and 1967 inferior conjunction, these observations suggest that the rotation period is 243.16 ± 0.02 days.

V. THOMSON SCATTER STUDIES

A. Observations and Analysis

A UHF system continues to operate twice a month for 24 hours and the L-band radar once a month for 12 hours.

Analysis of all data taken in 1965 is nearly complete. As distinct from 1963 and 1964, when the sunspot activity was low, there were a number of magnetic disturbances in 1965. This necessitates sorting the data into quiet and disturbed periods and analyzing these separately.

The temperature measurements performed in February and March of 1967 have been analyzed. They show that heating of the local ionosphere can be recognized (as increases in electron temperature T_e) at Millstone as coinciding with the time of sunrise at the magnetic conjugate point. Photoelectrons which escape the F-region in the southern hemisphere and travel

to the northern hemisphere following the magnetic field line are responsible for this effect. At Millstone the phenomenon is less pronounced than at Arecibo. This is attributed to the greater amount of heat stored in the "tube of force" connected to Millstone, which serves to maintain the local ionosphere warm throughout the night, and hence keeps the thermal conductivity of the F-region electrons high.

Thc above results also account for a number of variations of the f_oF2 at dawn in terms of variations in the electron loss coefficient resulting from changes in T_e. In winter, T_e increases first at conjugate sunrise, whereas in summer, T_e increases first at local sunrise. Hence the summer and winter behavior that initially appeared strangely different now can be explained by the effects of conjugate-point heating, together with the T_e control of the loss rate.

B. System Improvements

A new spectrum analyzer system is under construction in which the filtering will continue to be analog but the integration will be digital. Late delivery of the new filters, together with shortage of construction time, has slowed the work. However, the scheme should be brought into operation during the next quarter. The new system will eliminate recording the receiver IF signals for later analysis, since all possible delays will be examined at the same time.

New parametric amplifiers were received late in January and are currently being installed. Upgrading of the receiver system by replacing vacuum-tube IF amplifiers and mixers with solid state versions continues – albeit at a slow pace.

VI. RADIOMETRIC TECHNIQUES

A. Instrumentation

The principal developments in radiometric instrumentation have been the recalibration of the Haystack antenna pointing following rerigging and the integration of the Millstone analog pointing computer into that system.

Since the most recent pointing calibration at 15.5 MHz (2-cm wavelength), the Haystack system can now be pointed, reproducibly, at specified celestial coordinates with thc standard deviation of 0.003°, which includes all instrumental and refraction corrections.

With the analog pointing system at Millstone it is now possible to make spectral line observations with the Millstone antenna, time-sharing the Haystack Univac 490 between real-time control of the Haystack planetary radar and the processing of radiometric spectral line data from Millstone.

The Millstone-Haystack spectral line interferometer has been calibrated and used in observations during this quarter. A new spectral line program for the Univac 490 has also been completed, tested and used. This program eliminates the need for switching the radiometer input between the antenna and a load, thereby giving a 20°-to-30°K reduction in system temperature.

B. Evaluation of Rerigged Haystack Antenna

The Haystack antenna returned to operational use on 13 November 1967 after a surface readjustment program that began on 25 September. Optical measurements taken in the zenith position indicate an RMS deviation of about 0.020 inch from a best-fit parabaloid. Rerigging

was carried out to optimize the surface for elevation angles between 20° and 70° and computations yield an estimated RMS deviation of 0.017 inch in the 45° position.

Radiometric evaluation of the antenna began with a check of the focus by observing a point radio source with the subreflector at a sequence of different distances from the main reflector surface. The optically determined focal position was confirmed as the correct focal position for antenna operation. Measurements of a number of bright small-diameter radio sources were then made at 15.5 GHz (2-cm wavelength). At this frequency, there was increase in gain of about 40 percent. Radiometric mapping techniques using the brightest of these sources disclosed that in addition to the gain increase, the antenna pattern now appears axially symmetric about the main beam and the side-lobe structure is strongly depressed.

Using the pattern transmitter on Pack Monadnock mountain, the performance of the antenna at 35 GHz was measured. Previous to rerigging, similar measurements showed no well-defined main beam. Following rerigging, there was a well-defined main beam with the highest side lobe 9 db down from the on-axis gain. The antenna is now usable for measurements at this frequency. On the basis of radiometric measurements, the initial estimate of the overall RMS deviation is 0.030 to 0.035 inch. The reasons for the apparent discrepancy between the optical and the radiometric determinations of errors are under investigation, but in any event a near-spectacular improvement in antenna capability has been achieved.

C. Evaluation of ALTAIR Antenna (Project PRESS)

The equipment, measuring and processing techniques developed in radio astronomy as a part of the General Research Program will be applied in the calibration of the ALTAIR antenna. A radiometric system is being assembled and tested at Haystack. Upon completion of these tests, the radiometer will be installed in the ALTAIR for measuring the antenna pattern and efficiency, and for calibrating the pointing system.

D. Radio Astronomy

Observations of radio sources have continued at several different wavelengths. A map of the Orion nebula with a resolution of 2 minutes of arc has been prepared. The Haystack-Millstone interferometer has been used to measure the offset between the OH emission region in the source W3 and the weak continuum component of this source, which nearly coincides with the OH emission. This interferometer system has also been used to investigate the angular structure of the OH absorption in the direction of Cassiopeia A and to determine the positions of the two OH emission points in the source NGC 6334. Measurements of the time-varying radio sources – quasars, peculiar galaxies, and certain OH sources – were continued. Initial measurements were made in a program to determine the astronomical unit by observing the Doppler shift in the several bright OH emission sources.

Investigations with the very long baseline interferometer which makes use of independent frequency standards have continued. The 84-foot antenna at Onsala, Sweden, was added to the group of stations* at which these observations are made. OH spectral line observations with

* NRAO, Green Bank (140-foot)
Hat Creek, California (85-foot)
Millstone (or Haystack)

these four antennas have been processed on the CDC 3300 computer at Haystack. For the source W3, we obtained fringes with the Haystack-Onsala combination, a separation of 5507 kilometers, which is the longest baseline used successfully thus far. Detailed analysis of the very long baseline data obtained during the previous quarter has shown that the OH emission from W3 is confined to a region about 1 second in diameter with individual features being distributed in this disk. Some of the individual OH emission features have still not been resolved, their size being smaller than 0.003 second of arc.

VII. SPACE COMMUNICATIONS

The work reported below is under the direction of a member of the Space Communications program of the Laboratory. The role of Group 31 lies in consultation and planning, and in support of the work with the Station facilities.

A. Meteorological Effects

Data reduction is now in progress for summer rain measurements made using the Haystack and Millstone facilities. Preliminary results show excellent agreement between calculations and measurements of sky temperature made at X-band with the Haystack radiometer. The calculations are based upon L-band weather radar measurements made at Millstone and a statistical relationship between the continuation coefficient and backscatter computations based on drop-size data. Good agreement between the sky temperature measurements and calculations implies that the attenuation at X-band, caused by rain, can be adequately estimated by means of weather radar data.

B. Clear Air Observations

The theory of atmospheric turbulence predicts the existence of thin horizontal layers characterized by a randomly fluctuating index of refraction. Recent radar measurements have confirmed the existence of these layers in the lower atmosphere. Measurements made this winter by the Millstone L-band radar show that these turbulent layers also exist in the lower stratosphere. Similar layers have been detected up to 75,000 feet.

The thin turbulent scattering layers are one of the causes of tropospheric scattering at microwave frequencies. They are also responsible for amplitude scintillations on microwave line-of-sight paths through the atmosphere. Scintillation measurements were made at X-band using a beacon in the IDCSP satellite and the Westford Communications Terminal. Positive correlation has been established between the occurrence of the high altitude scattering layers and large amplitude scintillations. Plans are being formulated to determine the relationship of the clear air echoes to clear air turbulence of significance to the flight of aircraft.

RADAR
DIVISION 4

INTRODUCTION

General Research activities in Division 4 are carried out by Group 46 and deal primarily with advanced instrumentation for high-performance microwave components; work for the period from 1 November 1967 through 31 January 1968 is summarized in this section. The principal activities of the Radar Division are described in reports on RDT, PRESS, and BMRS. Other smaller programs are described in reports on space communications and radar studies of the moon.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 November 1967 through 15 February 1968

PUBLISHED REPORTS

Journal Article*

JA No.			
3020	Mounted Diode Equivalent Circuits	W. J. Getsinger	IEEE Trans. Microwave Theory Tech. MTT-15, 650 (1967)

* * * * *

UNPUBLISHED REPORTS

Journal Article

JA No.			
3095A	Computer-Design of Diode-Using Microwave Components, and a Computer-Dimensioned, X-Band Parametric Amplifier	W. J. Getsinger A. H. Kessler	Accepted by Microwave J.

* Reprints available.

MICROWAVE COMPONENTS
GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave needs of the Laboratory. Contributions are made to the General Research Program through the support of the Haystack Microwave System, operation of a high-power microwave laboratory, study of the problems of solid-state diode-using devices and techniques for computer design of these devices, studies of very-high-gain antennas and antenna feeds, and participation in a millimeter-wavelength program.

II. DIODE-USING DEVICES

A. Diode Measurements

Machining has been completed on the 30-inch-diameter, radial transmission-line cavity, which will be used to measure the equivalent circuit element values of packaged diodes at frequencies from 6 to 40 GHz. The parts are being assembled for electrical testing.

B. Power Combiners

The 12-diode power combiner has been operated successfully as a high-power doubler from 500 to 1000 MHz. It has delivered an output of 100 watts at about 57-percent efficiency, using a flowing liquid dielectric for cooling. This was the same efficiency and twelve times the output power of a typical single diode operated on a copper heat sink. The maximum output power was limited by overheating of the diode junctions. The power-limiting switching action mentioned in the last quarterly technical summary was due to a number of minor technical difficulties, but mainly to unbalance among the three diode columns introduced by dissimilar, electrically-long, feed-through capacitors.

These results demonstrate that a series-parallel array of varactor diodes can be made to perform like a single diode of large power-handling capacity, and that liquid-dielectric cooling can be adequate for such diode arrays.

At present, design work is progressing on a power-combiner multiplier with an array conforming to an equiphase surface of a radial transmission line. This type of power combiner is capable of using a much larger number of diodes and of operating at higher frequencies than the 12-diode power combiner described above.

C. Low-Noise Balanced-Diode Mixers

The analysis of the balanced mixer in terms of a reversing switch model has been completed for the cases of the ideal ($f_{co} = \infty$, $R_s = 0$) and the nonideal (f_{co} = finite, $R_s \neq 0$) diodes, where f_{co} is the zero-bias cutoff frequency and R_s is the series resistance. This approach predicts

the possibility of realizing very low noise figures for the reversing switch configuration when the image frequency response is open-circuited and other intermodulation products are short-circuited. Table 4-1 lists the theoretical results for the reversing switch mixer at room temperature, excluding the external circuit losses, which depend on a particular design.

TABLE 4-1
THEORETICAL VALUES FOR BALANCED MIXER

Signal Frequency (GHz)	f_{co} (GHz)	Noise Figure (dB)	Noise Temperature (°K)
3	100	0.53	37.5
3	500	0.13	8.5
10	100	1.73	142.1
10	500	0.41	28.4
10	1000	0.21	14.2
35	500	1.28	99.5
35	1000	0.69	49.7

A low-noise mixer has been designed for use at 3 GHz, using 100 GHz diodes, and is being fabricated at the present time. In addition, tentative designs for use at 10 and 35 GHz have been completed. The final designs, however, are dependent on the exact electrical characteristics of the Schottky Barrier diodes, which are being purchased. The X-band mixer will be realized in an integrated microstrip circuit as well as a waveguide configuration. The 35-GHz mixer will be in a waveguide configuration in which it is proposed to use very high-Q dielectric (rutile) resonators in order to obtain the desired low insertion-loss filter characteristics.

D. Gain Saturation in Parametric Amplifiers

Measurements have been made of the output saturation characteristics of one of the computer-designed X-band parametric amplifiers described previously. The relative variation in the output power level with small-signal gain for 0.5 dB of gain compression agrees closely with that predicted by the theory derived for an abrupt-junction varactor. The absolute power levels at which 0.5 dB of gain compression occurs, however, are at variance with the theory. The source of this discrepancy is under investigation.

III. MILLIMETER-WAVELENGTH PROGRAM

The 35-GHz lunar radar has been in operation for about two months, transmitting circular polarization and receiving the opposite circular polarization. It is being used to measure the reflectivity of the moon as a function of angle of incidence. The two-way 3-dB beamwidth is 3 minutes of arc; the portion of the moon's projected disk that is examined by the beam is therefore about 1 percent of the whole. The transmitter tube easily generates 1300 watts, but operation of the radar has been at 800 watts because of uncertainty about the power-handling capability of the waveguide switches. The pulse length is 2.4 seconds, the round-trip time to the moon.

The receiver uses point-contact diodes in a balanced mixer; its noise figure for single-sideband operation is about 13 dB. Triple conversion beats the received signal from 34.56 GHz plus a Doppler shift to 2500 Hz. The output 3-dB bandwidth at 2500 Hz is 170 Hz, slightly more than the largest frequency smear that can be generated by the moon's libration.

Relative motion of moon and earth can generate Doppler shifts of many tens of kilohertz, and the Doppler frequency can change at several hundred hertz per minute. To maintain an output at 2500 Hz, the second LO is programmed, in accord with a prior calculation, to compensate for the Doppler shift introduced by reflection from the subradar point. The programmed values can be perturbed manually in order to accommodate the Doppler from other parts of the moon. A crude discrimination scheme indicates whether the Doppler compensation has been such as to put the return in the center of the 170-Hz passband of the receiver. Each pulse is treated as a separate experiment. Within limits, loss of signal because of poor Doppler compensation can be corrected by consulting the discriminator calibration. However, more than half of the returns have to be discarded. The system, though inelegant, is quite workable; however, an attempt at automatic LO adjustment is in progress.

The receiver output is squared, integrated for 2.4 seconds, and punched on an IBM card, along with several integrations of the noise alone. The difference should be proportional to the signal energy. Imperfections in this part of the system degraded the data obtained during December and January. Until data have been taken with the system in its present improved state, it is safe to say only that returns from the subradar point and the limb differ by between 5 and 10 dB, and that the return from the crater Tycho is anomalously large.

ENGINEERING
DIVISION 7

INTRODUCTION

The Engineering Division supports the Laboratory's General Research program by work at Haystack and Millstone Hill, by design of high-pressure devices for solid state research, and by development of an integrated circuit facility. At Haystack Hill, two significant accomplishments have been made: The 120-foot reflector surface has been re-rigged to achieve an RMS error of only 0.017 inch from the best-fit paraboloid, and the development of a closed-cycle cryogenic refrigerator system has resulted in the operation of one maser for 19-1/2 hours on a single helium fill. Meanwhile, steady progress is being made to develop the facilities and techniques for designing and fabricating intergrated circuits. A number of useful circuits have been produced.

J. F. Hutzenlaub
Head, Division 7

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK MASER

The number one maser which has been installed in the number three dewar for use in the Planetary Radar Box has been operating for 19-1/2 hours on a single helium fill. This is in agreement with the Laboratory tests prior to installation.

The number three maser is being evaluated prior to installation. It has already been tried in dewars number 1A and 2, with the same boil-off rate in both cases. Thus it appears that the maser has a thermal leak outside the dewar construction. Investigation of possible thermal leak areas is continuing.

Dewar number four, purchased from Cathy Enterprises, supplier of the original equipment, has been received after rework and is undergoing evaluation tests.

The study of the best way to improve the heat transmission of the maser for closed-cycle refrigerator operation awaits actual thermal data. These data are to be obtained by monitoring several discrete points on the maser structure during cool-down operation.

II. HIGH PRESSURE DEVICES FOR SOLID STATE RESEARCH

Space limitations imposed by the available test equipment have made it necessary to develop a small pressure vessel which will be able to contain pressures of 250,000 psi at liquid nitrogen temperatures. Since the properties of diamagnetic materials under these conditions are not clearly defined, bomb performance has had to be derived by experiments rather than by calculations. Thus a series of bombs has been developed to aid the Laboratory in its investigation of the effects of pressure and temperature on the magnetic behavior and/or nuclear resonance of materials.

III. TRACKING TELESCOPE

An existing 24-inch Cassegrainian telescope is being converted into a tracker by changing its fixed secondary mirror into a tiltable, rotating mirror. The mirror will be dynamically balanced at a speed of 4000 RPM and can be tilted either 1/10 or 1 milliradian.

IV. NEROC RADOME

Two radome models were tested in the Wright Brothers Wind Tunnel at M.I.T. The models were truncated spheres mounted on tangent cones: one model had a 75-percent truncated sphere and the other had a 63-percent truncated sphere. The height and the spherical diameters of both models were the same. They were tested under both uniform and gradient flow conditions. In the gradient flow tests, the velocity of the flow varied with height according to a power law having exponents of 1/6 and 1/4. The complete pressure distribution over each model was measured for each of three test conditions. The data have been reduced and a report is in preparation.

Several iterations of radome design were carried out. The design studies included development of the beam and hub geometry, an approximate stress analysis, development of the mechanical details, and the preparation of a set of control drawings. The most important of the iterations was a truncated sphere-cone having a spherical radius of 520 feet with an overall height of 480 feet and a 600-foot-diameter 0.8 truncated sphere. The result of these studies is described in a report which is in preparation.

Optimization studies are continuing, and it is expected that the size of the truncated sphere can be reduced to about a 560-foot-diameter 0.8 sphere by allowing a small amount of foundation blockage when the antenna is pointed at the horizon. Further work is being carried out in the development of computer techniques for radome analysis. By using these techniques, the sensitivity of the structural design to the variations in pressure distribution will be examined.

COMPONENT DESIGN AND DEVELOPMENT
GROUP 73

I. INTEGRATED CIRCUIT FACILITY

During this reporting period development and implementation of the major areas that are required for the overall integrated circuit facility have continued.

The various tasks undertaken have provided preliminary information on the yield, cost, reliability and limitations of our present process and fabrication techniques. The variability of many of these tasks, unlike production fabrication, indicates the need for process control and documentation. The availability and price of monolithic circuit chips and devices continue to be uncertain, and many companies appear to be evaluating their sales policy concerning semiconductor chips.

About 15 circuits or subsystems have been undertaken during this quarterly period and are either completed or near completion. In addition, several components of a devclopmental nature are in process. This type of undertaking requires close cooperation and discussion with the originator, and usually numerous models are necessary before the performance specifications are satisfactory. The total time required to fabricate a hybrid integrated circuit is presently much longer than desirable, primarily becausc processes are not yet well established, and the development of techniques is proceeding with actual circuit fabrication.

The integrated circuit layout is primarily a manual operation and represents a considerable part of the total processing time in developing an integrated circuit. A computer program that selects the optimum resistivity value of thick or thin film material for a particular circuit case is now in regular use and improves the preliminary layout time. Some developmental work has started in cooperation with Group 23 which enables rough layouts to be translated into high resolution artwork that will reduce the total layout time considerably.

The progress of the thin film and thick film processing sections can be divided into three main categories that are characteristic of the integrated circuit facility in general.

A. Microcircuit Fabrication

The following circuits have been fabricated by either thin or thick film techniques:

Level shift driver
Radiation amplifier
Discriminator
Univer and gated univer
Low power flip-flop
Multiple varactor circuit
Error correcting redundant flip-flop.

The univer and varactor circuits are examplcs of designs that depend intimately on the processing characteristics and require the fabrication of many models in achieving optimum performance.

Several new circuits under development include:

Phased array driver
14-stage shift register
LCM driver.

B. Special Processing

Equipment and techniques developed for microcircuit fabrication have been used to solve materials and processing problems within the Laboratory. The applications are numerous and varied but principally involve:

Metallization of glass, ceramic and single crystals by vacuum evaporation and sputtering
Coating of materials by electroplating
RF sputtering of dielectrics
Formation of dielectric films by anodization
Chemical milling and selective etching of materials
Cleaning of materials for special applications.

C. Evaluation and Developmental Work

Considerable effort has been directed to the evaluation of current thin film and thick film processes and the development of improved fabrication techniques and equipment. The following areas are under investigation:

Properties of film resistors
Encapsulation of thin film resistors
Techniques for trimming film resistors
Firing characteristics of thick film resistor pastes
RF sputtering of dielectrics.

The semiconductor processing section is proceeding with mask preparation and outside procurement of monolithic circuits. In addition, development of a beam lead interconnection process has been initiated which will, if successful, simplify present bonding methods and reduce packaging problems.

Final assembly and bonding procedures vary considerably from one circuit or subsystem to another, because of the large variation in materials and component types that are available in the fabrication of the hybrid integrated circuits. Eventually, specific processing procedures combined with additional experience should improve the final fabrication time.

CONTROL SYSTEMS
GROUP 76

I. HAYSTACK

Rerigging of the 120-foot Haystack reflector was completed. RMS error from the best-fit paraboloid, initially 0.037 inch, was reduced to 0.017 inch. This error is measured at night and extrapolated to a 45° elevation angle. Considerable improvement in antenna performance at high frequencies has been observed since the rerigging was completed. A technical note containing detailed information on the measurement techniques and results is in preparation.

A prototype variable displacement pump was ordered for evaluation as a prospective replacement for the antenna power drive servo valves. Extensive test-stand experimentation is planned to demonstrate that the new replenishing system, together with the variable displacement pump, will provide improved and more reliable servo performance.

II. MILLSTONE RADAR

Refined adjustment procedures were used to reduce output errors in the newly installed celestial-terrestrial coordinate converter to the following values:

	Traverse Error	Elevation Error
RMS	0.012°	0.008°
Average	0.011°	0.004°
Maximum	0.03°	0.02°

These errors were measured for a set of 120 representative target positions. They are somewhat less than errors calculated from the stated accuracies of the computing elements used in this instrument.

III. LASER TRACKERS

Manufacture of peripheral equipment required to upgrade the Millstone Nike-Ajax mount pointing system for the laser radar was completed. Numerous switching, command, and repeater modules are required to provide the flexibility and convenience desired when the mount is incorporated into the proposed laser-tracker complex. Mechanical modifications, including removal of the slip-ring assembly and installation of digital shaft angle encoders, are planned to insure the compatibility of this mount with the ultimate control system.

The pointing system of the Powertronics laser mount was refurbished to provide improved control for an urgent laser experiment. A completely new control system for this mount, including provisions for local and remote digital pointing, will be installed as time and availability permit.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 November 1967 through 31 January 1968. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 November 1967 through 15 February 1968

PUBLISHED REPORTS

Journal Articles*

JA No.			
3021	Localized vs Collective d Electrons and Néel Temperatures in Perovskite and Perovskite-Related Structures	J. B. Goodenough	Phys. Rev. 164, 785 (1967)
3024	Plasmas for High Temperature Chemistry	T. B. Reed	Advances in High Temperature Chemistry, Vol. 1 (Academic Press, New York, 1967)
3038	Long-Term Operation of a Sealed CO_2 Laser	R. J. Carbone	IEEE J. Quant. Electron. QE-3, 373 (1967)
3044	Optical Properties of the Metal ReO_3 from 0.1 to 22 eV	J. Feinleib W. J. Scouler A. Ferretti	Phys. Rev. 165, 765 (1968)
3049	Characterization and Structure of $La_4Re_6O_{19}$, a New Metal Cluster Compound	J. M Longo A. W. Sleight†	Inorg. Chem. 7, 108 (1968)
3065	Self-Steepening of Light Pulses	F. De Martini† C. H. Townes† T. K. Gustafson† P. L. Kelley	Phys. Rev. 164, 312 (1967)
3066	Magnetic Interactions and Spiral Ground States in Spinels, with Application to $ZnCr_2Se_4$	K. Dwight N. Menyuk	Phys. Rev. 163, 435 (1967)
3068	Theory of the Magnetic Properties of the Ilmenites $MTiO_3$	J. B. Goodenough J. J. Stickler	Phys. Rev. 164, 768 (1967)
3069	Magnetic Resonance and Susceptibility of Several Ilmenite Powders	J. J. Stickler S. Kern† A. Wold† G. S. Heller†	Phys. Rev. 164, 765 (1967)
3074	A 10.6-Micron Four-Port Circulator Using Free Carrier Rotation in InSb	J. H. Dennis	IEEE J. Quant. Electron. QE-3, 416 (1967)
3078	Infrared Heterodyne Detection	M. C. Teich	Proc. IEEE 56, 37 (1968)

* Reprints available.

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JA No.			
3086	The Gunn Effect in n-CdTe	M. R. Oliver A. G. Foyt	IEEE Trans. Electron Devices ED-14, 617 (1967)
3090	New Expansion for the Classical Heisenberg Model and Its Similarity to the S = 1/2 Ising Model	H. E. Stanley	Phys. Rev. 164, 709 (1967)
3097	Perturbation Calculation of Band-Structure Effects in Low-Field Helicon Propagation	A. L. McWhorter J. N. Walpole*	Phys. Rev. 163, 618 (1967)
3107	Mode Pulling in a Stimulated Raman Oscillator	P. E. Tannenwald	J. Appl. Phys. 38, 4788 (1967)
3110	A New, Widely and Continuously Tunable, High-Power Pulsed Laser Source	R. L. Carman J. Hanus D. L. Weinberg*	Appl. Phys. Letters 11, 250 (1967)
3139	Evidence for Electron-TO Phonon Interaction in InSb	D. H. Dickey D. M. Larsen	Phys. Rev. Letters 20, 65 (1968)
3148	Imaging and Storage with a Uniform MOS Structure	R. J. Phelan, Jr. J. O. Dimmock	Appl. Phys. Letters 11, 359 (1967)
3156	Critical Properties of Isotropically-Interacting Classical Spins Constrained to a Plane	H. E. Stanley	Phys. Rev. Letters 20, 150 (1968)
3174	Quartz Raman Laser	P. E. Tannenwald F. H. Perry	Laser Focus 3, 17 (1967)
MS-2009	Homogeneity Range and Concentration-Pressure Isotherms of HgSe	R. F. Brebrick A. J. Strauss	Proc. International Conference on II-VI Semiconducting Compounds (W. A. Benjamin, Inc., New York, 1967)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
3134A	Epitaxial Gallium Arsenide for High-Efficiency Gunn Oscillators	C. M. Wolfe A. G. Foyt W. T. Lindley	Accepted by Electrochem. Technol.
3149	Magnon-Phonon Coupling in Metallic Films	R. Weber	Accepted by Phys. Rev.

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JA No.			
3154	Magnetic Ordering and the Electronic Properties of the Heavy Rare Earth Metals	R. E. Watson* A. J. Freeman* J. O. Dimmock	Accepted by Phys. Rev.
3162	Design and Short-Term Stability of Single-Frequency CO_2 Lasers	C. Freed	Accepted by IEEE J. Quant. Electron.
3169	On Intense Mercury Vapor Green Band Emission	R. J. Carbone M. M. Litvak	Accepted by J. Appl. Phys.
3176	Dependence of Critical Properties on Dimensionality of Spins	H. E. Stanley	Accepted by Phys. Rev. Letters
3185	Self-Trapping in Media with Saturation of the Nonlinear Index	T. K. Gustafson* P. L. Kelley R. Y. Chiao* R. G. Brewer*	Accepted by Appl. Phys. Letters
3187	Isotope Effect in Superconducting Rhenium	E. Maxwell* M. Strongin* T. B. Reed	Accepted by Phys. Rev.
3191	Continuous Operation of a Long Lived CO_2 Laser Tube	R. J. Carbone	Accepted by IEEE J. Quant. Electron.
MS-1954	Localized vs Collective Descriptions of Magnetic Electrons	J. B. Goodenough	Accepted by J. Appl. Phys.
MS-1955	Magnetic Properties of $SrRuO_3$ and $CaRuO_3$	J. M. Longo P. M. Raccah J. B. Goodenough	Accepted by J. Appl. Phys.
MS-1956	A Localized-Electron ⇄ Collective-Electron Transition in the System $(La, Sr)CoO_3$	P. M. Raccah J. B. Goodenough	Accepted by J. Appl. Phys.

Meeting Speeches†

MS No.			
1882C	Raman Scattering from Plasmons and Phonons: Experimental	A. Mooradian	Conference on Nonlinear Interactions in Solids, Newport Beach, California, 15 – 19 January 1968
1882D	Raman Scattering from Plasmons and Phonons	G. B. Wright	Colloquium, Polytechnic Institute of Brooklyn, 2 February 1968
1954A	Localized vs Collective Descriptions of Magnetic Electrons	J. B. Goodenough	Interdisciplinary Seminar, Stanford University, 18 – 19 January 1968

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† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Division 8

MS No.			
1980A	Modern High Pressure Techniques	J. A. Kafalas	ASM, High Pressure Treatment of Materials, ManLabs, Inc., Cambridge, Massachusetts, 15 – 17 November 1967
2015A	Survey of Equipment for High Pressure Studies	M. D. Banus	
2016A	Retained High Pressure Phases and High Pressure Synthesis	M. D. Banus	
1996B	Electron-Beam-Pumped Semiconductor Lasers	C. E. Hurwitz	Colloquium, Cornell University, 7 February 1968
2111	Magnetoreflectivity of Bismuth	M. S. Maltz M. S. Dresselhaus	American Physical Society, New York, 16 – 18 November 1967
2141	Zero Gap Semiconductors	S. H. Groves	
2146	Band Structure, Preparation, and Device Potentialities of $Hg_xCd_{1-x}Te$ and $Pb_{1-x}Sn_xTe$	T. C. Harman	
2131	On Emission and Absorption by Excited OH Λ-Doublet States	B. Zuckerman* D. F. Dickinson* M. M. Litvak	American Astronomical Society, University of Pennsylvania, 4 – 7 December 1967
2138	Raman Scattering from Elementary Excitations in Solids Using Lasers	A. Mooradian	Seminar, M. I. T., 17 November 1967
2141A	Zero Gap Semiconductors	S. H. Groves	Seminar, Tufts University, 19 January 1968
2149A	Infrared Detection and Imaging Using an InSb MOS Structure	J. O. Dimmock	Seminar, Harvard University, 6 December 1967
2151	Critical Properties of the Vaks-Larkin Model for the λ Transition in a Bose Fluid	H. E. Stanley	Statistical Mechanics Meeting, Yeshiva University, 15 November 1967
2153	CO_2 Laser Systems: Generation, Transmission and Detection of Coherent Infrared Waves	R. H. Kingston	Colloquium, Columbia University, 12 January 1968
2162	Band Structure, Materials Preparation and Device Possibilities in the Pb-Sn Salt Systems	T. C. Harman	Seminar, P. R. Mallory & Co., Inc., Burlington, Massachusetts, 6 December 1967
2164	Infrared Imaging and Memory with an InSb MOS Structure	R. J. Phelan, Jr.	Seminar, M. I. T., 1 December 1967

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MS No.			
2209	Growth, Annealing, and Properties of Lead-Tin Chalcogenides	T. C. Harman	Industrial Liaison Symposium on Electronic Materials and Devices, M.I.T., 13 February 1968
2229	Lead-Tin Chalcogenide Infrared Detectors and Lasers	I. Melngailis	
2258	Infrared Detection, Imaging and Storage Using an InSb MOS Structure	R. J. Phelan, Jr.	
2259	Growth of Epitaxial GaAs for X-Band Gunn Effect Oscillators	C. M. Wolfe	
2215	Electronic Raman Scattering from Impurities in Semiconductors	G. B. Wright	Conference on Nonlinear Interactions in Solids, Newport Beach, California, 15 – 19 January 1968
2239	Raman Scattering from Plasmons and Phonons: Theoretical	A. L. McWhorter	
2223	Electronic Structure of Nickel: Theory and Experiments	J. Hanus	American Physical Society, Chicago, 29 January – 1 February 1968
2224	Interpolation Scheme for Energy Bands in Cu and Ni	G. F. Dresselhaus J. Hanus	International Symposium on Atomic, Molecular, and Solid State Theory and Quantum Biology, Sanibel Island, Florida, 15 – 20 January 1968
2228	Interpolation Methods for Phonon Spectra in Crystals	G. F. Dresselhaus M. S. Dresselhaus	
2230	Spin Resonance in Magnetic Spiral Structures	H. J. Zeiger	Seminar, Boston College, 17 January 1968
2249	Ultraviolet and Infrared Pumping of OH Molecules	M. M. Litvak	HII Region Symposium, Charlottesville, Virginia, 8 – 11 December 1967

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Type conversion and p-n junctions have been produced in n-type CdTe by implantation of 400 keV As^+ ions. The CdTe samples were pre-annealed in Cd vapor, in order to insure n-type conductivity, and coated with ~1500 Å of SiO_2 so that they could be heated to 500°C during implantation. Following implantation, the SiO_2 was removed and each sample was annealed at 650°C with CdTe powder and Cd. Hall effect measurements and DC thermal probe tests indicate that the implanted region was converted to p-type while the unimplanted region remained n-type. The diodes between the implanted and unimplanted regions had sharp reverse breakdowns at 40 to 50 volts, forward resistances of 30 ohms, and in forward bias emitted bandgap infrared radiation. Similar experiments using a 400 keV Ar^+ ion beam gave no evidence of type conversion.

The volt-ampere characteristics of a number of diodes fabricated from vapor-grown annealed $Pb_{1-x}Sn_xTe$ have been greatly improved by electrolytic etching. For example, the zero-bias impedance of one $Pb_{0.85}Sn_{0.15}Te$ diode was increased from 3 ohms to approximately 2000 ohms at 77°K and to approximately 5000 ohms at 12°K. The present results indicate that the surface condition of $Pb_{1-x}Sn_xTe$ diodes plays an important part in determining the zero-bias impedance and that this impedance can, in some devices, be increased substantially by suitable surface preparation. This offers the possibility of greatly improving the performance of $Pb_{1-x}Sn_xTe$ photovoltaic detectors and lasers.

The spectral response of an InSb-MOS photovoltaic detector has been studied at 77°, 195° and 300°K in the wavelength region between 2.5 and 0.25 μ. A photovoltage developed across the MOS structure is observed at wavelengths between 1.25 and 0.25 μ, with a single broad peak at about 0.3 μ. Measurements of the response of the MOS detector to near-IR radiation while the detector is being irradiated with light of a different energy indicate that there are long-lived states of the detector which can be changed by irradiating the detector with light of wavelengths less than 1.25 μ. We expect to find that this effect is related to the MOS detector response in the infrared and to the photovoltage observed around 0.3 μ.

A number of CdS platelets were grown in a flowing hydrogen atmosphere with elemental cadmium and sulfur as source materials. Resistivity and Hall constant measurements at 300° and 77°K indicate that undoped as-grown CdS platelets with good electrical properties can be obtained using this growth process.

A technique has been developed for etching patterns in silicon nitride layers using a thin layer of silicon as an etch mask. This layer is deposited over the silicon nitride using the same reactor system as was used in depositing the silicon nitride. Patterns are etched in the silicon over-layer using standard photolithographic techniques, and concentrated HF or hot phosphoric acid can then be used to remove the exposed areas of silicon nitride. These same steps can be used to etch openings in layered structures of silicon nitride over silicon dioxide. In this case hot phosphoric acid should be used as the etchant for the silicon nitride.

II. OPTICAL TECHNIQUES AND DEVICES

A nine-meter-long CO_2 10.6-μm amplifier has been operated at greater than 100 W output power with an input power of only 5 W. The power efficiency was 11.5 percent. The water cooled tubes utilized a flowing gas mixture, and no appreciable beam (mode) distortion was observed by means of a thermally sensitive detector.

In the preliminary tests of a scaled-up sealed-off laser, single frequency output powers up to 15 W have been obtained. Spectrum analyzer displays of the beat note indicated a short-term frequency stability of the same order of magnitude as previously observed with two 1.5-Watt tubes.

Background limited operation of copper-doped germanium detectors has been obtained for a background as low as 10^{-11} W (5×10^8 photon/sec) in the 8- to 12-μ region. A cooled FET circuit permits the measurement of these low backgrounds. Preliminary measurements of response vs temperature indicate two regions of near-linear behavior: one region between 4.5° and 7°K and another between 8° and approximately 12°K, with a transition region between 7° and 8°K.

Preliminary experiments have been performed to determine the feasibility of using a pair of semiconductor p-n junction lasers, one of which is "tuned" by a magnetic field, to produce heterodyne IF frequencies extending continuously into the GHz range. Mode spectra of several PbTe units have been obtained, one of which exhibited single-mode CW operation. Also, the stability of the wavelength of coherent emission from a diode laser has been analyzed.

Excess noise and anomalous gain have been observed in Ge:Cu photodetectors at frequencies small compared with the reciprocal carrier lifetime. These are attributed to minority carrier injection at the contacts. In heterodyne operation, amplitude fluctuations of the laser local oscillator are found to be troublesome, even at tens of megahertz.

III. MATERIALS RESEARCH

An open-tube reactor has been constructed for synthesizing compounds of volatile elements at essentially constant pressure by repeatedly dropping small amounts of the reaction mixture into a crucible hot enough to produce rapid vaporization and reaction. Use of this apparatus has made it possible to produce such compounds as ZnTe and ZnSe at the rate of 100 to 300 g/h, without the risk of explosions which frequently occur when volatile elements are reacted in closed ampoules.

Forced convection in an open tube has been used for the vapor growth of $Pb_{1-x}Sn_xTe$, $ZnTe_{1-x}Se_x$, and Cd_3As_2 single crystals about 1 to 10 mm on a side. Helium and hydrogen were used as carrier gases to obtain vapor transport rates higher than those achieved by diffusion or natural convection in closed systems.

Partial pressures of $Te_2(g)$ and SiTe(g) in equilibrium with Si-Te samples containing between 10 and 100 atomic percent Te have been determined by measuring the optical density of the vapor for sample temperatures between 500° and 940°C. The results confirm the existence of $Si_2Te_3(c)$ as the only solid compound in the Si-Te system, and yield values for the free energies of formation of $Si_2Te_3(c)$ and SiTe(g).

The high-pressure phase diagram of InSb has been further investigated by means of superconducting transition temperature and x-ray diffraction measurements on the three high-pressure phases, InSb-II, InSb-III and InSb-IV. The locations of the II-III and II-IV phase boundaries have

been established. The structure of InSb-IV was found to be hexagonal, and lattice parameters have been determined for all three phases.

The atmospheric pressure phase of $RbNiF_3$, which is hexagonal and ferrimagnetic, has been transformed into a high-pressure phase by subjecting it to a pressure of 65 kbars at 600°C. The new phase has the cubic perovskite structure and is antiferromagnetic.

A new antiferromagnetic perovskite, $CaCrO_3$, has been prepared by the reaction of CaO and CrO_2 in a gold capsule at a pressure of 65 kbars and temperature of 700°C. The Néel temperature is 90°K at atmospheric pressure and has a pressure coefficient of -0.23°K/kbar. The negative pressure coefficient indicates that the compound exhibits spontaneous band antiferromagnetism.

The martensitic transition and elastic memory exhibited by TiNi have been explained in terms of a structural model which involves the formation of like-atom clusters in the low-temperature phase. Because of cluster formation, deformation of this phase takes place by one-jump slip on adjacent planes, rather than many-jump slip on a single plane. When the sample is heated above the transition temperature, the sample returns to its original shape, since the deformation is removed by one-jump slip in the reverse direction.

IV. PHYSICS OF SOLIDS

Exciton fine structure in the interband magnetoabsorption of germanium has been studied over a wide range of magnetic fields up to 80 kG. The data provide a means of connecting the exciton energy levels in the low field region to those in the high field Landau level region.

Far-infrared cyclotron resonance of free carriers in the conduction band of InSb has been observed at wavelengths of 195, 311 and 337 μ, using a cyanide gas laser as a source and the photoconductivity of the sample as a means of detection. At each wavelength a second absorption peak, associated with transitions between hydrogenic donor impurities, is found on the low field side of the cyclotron resonance peak.

Preliminary measurements have been made of 35- and 70-GHz microwave absorption in $Pb_{1-x}Sn_xTe$ alloys as a function of magnetic field. Two distinct effects have been found: magnetoplasma cyclotron resonance and Shubnikov-de Haas oscillations.

The continuing study of the effect of stress on the spectra arising from donor impurities in silicon has now been extended to bismuth-doped silicon. The effect of stress on the spin-orbit split triplet state has been examined. The value obtained for the pure shear deformation potential coefficient is about 10 percent lower than that previously measured for p-states in either sulfur- or phosphorous-doped silicon.

The theoretical form of the Γ_8 dispersion relations, $\mathcal{E}(\vec{k})$, for the zincblende lattice has been evaluated specifically for HgTe and HgSe by finding the eigenvalues of the 4×4 $\vec{k} \cdot \vec{p}$ interaction Hamiltonian. Some details of the calculated energy surfaces have been compared with experimental Shubnikov-de Haas measurements.

In more basic work, Bloch sums of localized atomic orbitals have been calculated for two one-dimensional models, one in which the orbitals are assumed exponential and the other, Gaussian. Closed-form expressions are obtained for various physical quantities and their properties are discussed in some detail. It is found that the effect of orbital overlap is usually greater on the momentum distribution than on the charge density in crystals.

The study of pressure effects on the magnetic properties of MnAs has continued. With MnAs in the high-pressure (B31) phase, the variation of magnetic moment with temperature at pressures ≥ 9 kilobars begins to resemble that of MnP, which is isostructural to the B31 MnAs.

In the continuing investigation of magnetic resonance in spiral spin structure compounds, a calculation of the ground-state spin configuration of $CoCr_2O_4$ indicates that a six- rather than a three-sublattice model is required to minimize the energy. Using this model, the resonant frequencies are being calculated. Also being investigated, as an aid in understanding resonance behavior in more complicated conical spiral systems, are the ground-state properties of a linear chain of two nonequivalent spins; this is the simplest model capable of describing a two sublattice conical helix spin configuration.

The Argyres-Kelley decoupling procedure for obtaining the reduced density matrix equations of motion for a system interacting with a bath and an external driving field has been used to find an expression for the contribution of a long wavelength spin wave to the susceptibility of a Heisenberg ferromagnet at low temperatures. The well-known spin-wave renormalization and scattering terms are obtained, and in the low temperature limit, the susceptibility due to spin wave has the same form as that obtained using Green's function techniques.

Considering only nearest-neighbor spin interactions, an exact solution for the energy, specific heat and susceptibility has been obtained for an open-linear chain of arbitrary-dimensional spins and also for a Bethe lattice of coordination number z. A new general Hamiltonian with arbitrary ν-dimensional classical spins and also arbitrary lattice has been set up. This Hamiltonian reduces to the Ising, Vaks-Larkin, Heisenberg and spherical models, respectively, for $\nu = 1, 2, 3$ and ∞.

Two new features have been observed in the continuing study of stimulated Raman and Brillouin scattering in quartz. A doublet, which can be attributed to coupling of the vibrational mode to the infrared, has been obtained in the Raman spectrum; and iterative backward-forward Brillouin shifts have been achieved directly in the sample without the usual laser reamplification process.

The phonon spectrum of CdTe has been studied at 300°, 77° and 4.2°K by Raman scattering at 1.06 μ and far-infrared absorption. The Raman studies of the two-phonon spectrum, with polarized light and oriented single crystals, exclude the decay of a virtual zone center phonon through the anharmonic phonon interaction as an important Raman process.

Study of the time dependence of thermal defocusing of a laser beam continues. Depending on certain conditions, the change in beam size with time, t, investigated with a motion picture camera, varies either linearly with t, or as $t^{1/2}$.

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This Quarterly Technical Summary covers the period from 1 November 1967 through 31 January 1968. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

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